

CALIFORNIA DIVISION OF MINES AND GEOLOGY
FAULT EVALUATION REPORT FER-185

SURFACE RUPTURE ASSOCIATED WITH THE NORTH PALM
SPRINGS EARTHQUAKE OF JULY 8, 1986--BANNING AND
RELATED FAULTS, RIVERSIDE COUNTY

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August 7, 1987

INTRODUCTION

An earthquake of M_L 5.9 occurred at 2:21 A.M. on July 8, 1986, 10km northwest of North Palm Springs. Although the earthquake was centered near the Mission Creek fault (Figure 1), most of the associated surface faulting occurred along the Banning fault. Minor tectonic rupture also apparently occurred along short segments of the Mission Creek and Garnet Hill faults.

Following the earthquake, DMG geologists responded to document and map the extent of surface faulting, as well as to observe the effects of the earthquake. Mike Manson and Glenn Borchardt, who were staying in nearby Yucca Valley, arrived at the Banning fault at 7:15 A.M. Jim Kahle arrived at the Banning and Garnet Hill faults in Whitewater Canyon about 7:30 A.M. from Los Angeles and was joined on July 10 by Earl Hart from the Pleasant Hill office. Together, we systematically checked the various faults for surface rupture and made other observations of secondary ground failure and structural damage through July 11. Kahle returned to make additional observations July 16 to 18 and Manson on July 22.

The main purpose of this report is to document the observed evidence of surface faulting observed by the DMG team. A secondary purpose is to assess the Special Studies Zones Maps that had been issued previously (CDMG, 1974 and 1980).

Pertinent reports on the North Palm Springs (NPS) earthquake and its effects include preliminary summaries by EERI (1986), Borchardt and Manson (1986), Jones and others (1986), and Sharp and others (1986). The latter reference assesses the surface faulting observations of the USGS, but omits detailed descriptions and maps.

TECTONIC SETTING

The North Palm Springs earthquake occurred along a wide and very complex segment of the San Andreas fault zone where its trend changes from northwest in the Coachella Valley to more westerly in the San Bernardino Mountains (Figure 1). The principal elements of this zone are the Mission Creek and Banning faults (Proctor, 1968; Allen, 1957), both of which are steeply dipping right-lateral strike-slip faults in Coachella Valley. Geomorphic and other evidence of recent activity on the Mission Creek fault diminishes northwest of

Desert Hot Springs and activity apparently steps left to the Banning fault (Clark, 1984; Reeder and Rasmussen, 1986). According to Allen and Sieh (1983), the Banning fault has had about 2mm/yr of right-lateral creep near Devers Hill since 1972 based on an alignment survey (Figure 1). In the vicinity of Whitewater River, both the Banning and Mission Creek faults dip 60-70°N and have significant reverse components of slip (Allen, 1957). Farther to the west, the Banning fault becomes a low-angle thrust (Allen, 1957).

The Garnet Hill fault (Figures 1 and 2), south of the Banning fault, is largely concealed by alluvium, but is considered to be a high-angle right-lateral fault (Matti and others, 1985; Proctor, 1968). The northwest end of the fault is marked by a south-facing scarp in alluvium near Whitewater (Smith, 1979b). To the west, this fault merges complexly with the San Gorgonio Pass fault of Smith (1979b) and Matti and others (1985) (Figure 1). The latter fault is a complex, north-dipping thrust fault that locally offsets young alluvium. Only those segments of the Garnet Hill and San Gorgonio Pass faults shown on Figure 2 were zoned for Special Studies.

North of and parallel to the Mission Creek fault is the Mill Creek fault (Figure 1), which Matti and others consider to be inactive. To the northeast of the left bend in the Mission Creek-Mill Creek fault is the left-lateral Pinto Mountain fault, which apparently has deflected the San Andreas fault zone, forming or contributing to the compressional knot formed in the epicentral region. The northeast-trending Morongo Valley fault may be a branch of the Pinto Mountain fault, but it has had late Quaternary uplift on the southeast (Matti and others, 1985). Proctor (1968) and Dibblee (1967) mapped these faults somewhat differently from Matti and others.

The minor, northeast-trending faults near Highway 62, between the Banning and Mission Creek faults (Figure 1), are considered by Matti and others (1985) to be extensional features of Pleistocene age but probably are not Holocene. Of these minor faults, only the "Devers Hill" fault was zoned for Special Studies (Figure 3), based on the work of Smith (1979a). Matti and others (1985) have attempted to integrate the work of others and to summarize the neotectonics of this very complex region. Although some of their conclusions are somewhat speculative and not fully documented, they do provide considerable insight regarding the modern tectonics of the epicentral region of the NPS earthquake.

The relationship of the NPS earthquake and its aftershocks to the above faults is shown in Figures 5 and 6. According to Jones and others (1986), the main shock had a focal depth of 11.3 km and a preferred focal plane of N60°W, 45°NE. The first motion on this plane indicates pure right-lateral slip. The data generally suggest the Banning fault as the causative earthquake fault. This is further supported by the aftershocks, which plot on a plane that dips 50-60°NE (Figure 6). However, the aftershock plane does not extend within 4km of the surface.

SURFACE FAULTING

The range of ground failure effects observed after the NPS earthquake was generally commensurate with the terrain and the reported magnitude ($M_L 5.9$) and maximum accelerations (0.78g at North Palm Springs, 0.97g at Devers Hill Substation). Failures included rock and soil falls on steep slopes, slumps in road fill, scattered landslides, shattering of soil and ridge tops, differential settlement in soft alluvium, and rocking of boulders in their nests. These failures occurred throughout the epicentral area, but no effort was made to systematically document them by DMG. It was noted, however, that an unusual amount of ground failure (mostly extensional cracks in soil) occurred on or very close to the mapped or projected traces of the Banning and other faults. The coincidence of shaking failures with faults strongly suggests that the fault zone served to focus shaking or at least was enhanced by tectonic deformation along the faults. The reasons for this are unclear, although the phenomenon has been noted after other earthquakes in California (e.g., 1973 San Fernando E/Q, 1980 Livermore E/Q, 1983 Coalinga E/Q).

Accessible parts of the Banning, Mission Creek, Garnet Hill, San Geronio Pass and "Devers Hill" faults were checked for surface faulting in the epicentral area. Surface ruptures that could be reasonably attributed to faulting were observed along the first three named faults. As in other recent earthquakes, surface faulting was confined to pre-existing faults as evidenced by coincidence of rupture with fault-produced geomorphic features. However, the zone of tectonic rupture appeared to be unusually wide along the Banning fault (locally up to 100 m or so), although the zone was partly obscured by shaking fractures. These ruptures are summarized by Sharp and others (1986), who referred to the incipient tectonic ruptures on the Banning fault as "trace fracturing." They considered the similar minor fractures along the Garnet Hill and Mission Creek faults to be due solely to shaking. Our observations are summarized below and details are presented in Table 1 and Figures 2, 3 and 4.

Banning Fault

Clear evidence of surface faulting occurred somewhat discontinuously along a 4.7 km segment of this fault east of the western boundary of the Desert Hot Springs quadrangle (Figure 3, localities 7 to 20). Very discontinuous crack zones as much as 3.4 km to the west also may be related to faulting (localities 3, 5 and 6, Figure 2). In addition, Sharp and others (1986) reported cracks at two additional locations as much as 2 km to the southeast of our observed ruptures (Figure 3). The main evidence for tectonic rupture is the left-stepping pattern of open fissures with systematic right-lateral extension. A disproportionate number of cracks were oriented clockwise to the mapped trend of the fault, even where left-stepping sets could not be observed. The maximum amount of right-slip was measured along the pavement of State Highway 62, (yellow and white lines of northbound lanes) where five cracks in a zone 52 m wide had a cumulative right-lateral displacement of 6.6 cm on 7/9/86 (locality 13). This was slightly greater than measurements made the preceding day, suggesting that some afterslip occurred. An additional 0.6

cm cumulative right-slip was measured on two of four other cracks as much as 93 m further north on 7/9/86 (not observed 7/8/86). Thus, the cumulative right slip measured on 9 cracks in a zone 145 m wide was 7.2 cm. A similar amount of offset was not noted in pavement of the southbound lanes of Highway 62, although fill there appeared to be thicker than in the northbound lanes. The USGS measured 9 cm of cumulative offset for cracks in the northbound highway pavement or curb, but they do not indicate when their observations were made (Sharp and others, 1986). However, an alignment survey of the eastern curb showed an anomalous 2 cm of left-lateral deflection. A similar survey of the west curb in the southbound lanes showed 0 to 1.8 cm of right-lateral offset across the fault. This suggests to us that elastic strain (probably shallow) must have developed along the fault prior to construction of the highway and subsequent strain release was then triggered by seismic shaking. As much as 4 cm of right-slip was observed along left-stepping cracks and pavement both east (locality 15) and west (locality 12) of the highway.

In addition to right-slip displacement along the Banning fault, there was local evidence of reverse displacement east of Highway 62 (localities 14, 16 and 18). Mostly, this consisted of low, narrow compressional features with closed cracks, although several north-dipping fissures with as much as 5 to 10 cm of reverse displacement (up on north) were noted at or near the base of south-facing scarps.

Extensional cracks were widespread along the Banning fault and it was generally not possible to distinguish between those caused by faulting or tectonic stretching and those caused by shaking (downslope movements, settlement, and lateral spreading). We suspect they largely can be attributed to shaking. However, the continuity of some of the zones of cracks across varied terrain and the alignment of cracks along linear fault topography suggest that some of the extensional cracks may be associated with pre-existing faults.

That the observed ruptures may reflect a relatively wide zone of complex faulting is suggested by two other lines of evidence. First, the geomorphic evidence for recent faulting locally suggests a relatively wide zone with several faults dominated by right-lateral displacements. These traces are shown on the Special Studies Zones map of the Desert Hot Springs quadrangle (Figure 3) which was based on unpublished mapping of Smith (1979a). His mapping is rather similar to that of Clark (1984). Second, and perhaps more compelling, are the trench logs of Gary Rasmussen (1981, 1983) which are based on trenches excavated in Section 9 north of Dillon Road. These logs clearly show that the Banning fault is a complex zone of faults that is 50 m to more than 100 m wide (Figure 7). Although most of the faults are steeply dipping, some dip to the south and north as gently as 17 degrees. The mismatched strata across these faults indicate that strike-slip displacement is dominant, although some faults show significant normal and reverse offsets. At Super Creek, another trench (locality 7) shows a 62-meter-wide zone of faults that offset Holocene alluvium (Soil and Testing Engineers, 1987)

Mission Creek fault

A 200-meter-long zone of cracks was mapped by us on 7/11/86. The cracks were noted on Highway 62 by the morning of July 8 by DMG, and presumably were

coseismic. The zone trends about N80°W, extending westward from Twentynine Palms Road to a point about 100 m west of Highway 62, ending in an artificial cut in Plio-Pleistocene rocks veneered with slope wash. Although cracks were reported as much as 500 m to the west of the highway by the USGS (Rob Wesson, p.c., 7/11/86) we were unable to verify this. Cracks were also reported in the hill 300 m to the east of the highway (G. Rasmussen, p.c., 7/11/86), but we were unable to follow the zone across the wash. Although our observations were somewhat cursory, we did note that a large number of cracks had systematic left-lateral displacement as much as 2 to 4 mm. Moreover, some of the cracks west of the highway were right-stepping and had a trend somewhat counterclockwise to the crack zone.

A maximum cumulative left-lateral displacement of 1.5 to 2 cm was observed on two fractures in the southbound lanes (west curb) of the Highway. These fractures were about 16 m apart, somewhat sinuous, and had a westerly trend. According to Rob Wesson (USGS, p.c., 7/11/86), the northerly crack appeared to have 2 to 3 mm greater offset than when observed the previous day, suggesting some afterslip. However, the amount of slip observed in old and new highway pavements to the east (as well as the thickness of the road fill in the new highway) appears to be less, which suggests that the offsets in the southbound pavement may have been affected by lateral spreading due to shaking. Alternatively, the zone of cracks to the east was fairly wide--about 30 to 45 m in the old pavement of Twentynine Palms Road--which could have effectively obscured 1 or 2 cm of distributive left-slip. Other accessible points along the fault were checked to the west and east of Highway 62 (Figure 1), but no fresh cracks were found.

Although the cracks along the Mission Creek fault were somewhat ambiguous and did not have the expected right-lateral displacement, the systematic left-lateral slip suggests a tectonic origin. We cannot explain this phenomenon and cannot even document if it was coseismic. However, the fact that the cracks formed generally along the projected trace of the Mission Creek fault and occurred in fill, older alluvium and bedrock on relatively flat surfaces suggests a tectonic cause.

Garnet Hill fault

A segment of this fault was previously mapped by Allen (1957) as a surface feature in the Whitewater quadrangle and verified as a broad, south-facing scarp in older alluvium at the mouth of Whitewater Canyon by D.P. Smith (1979b). Only a short segment of the fault was zoned by DMG (Figure 2). The concealed projection of the fault to the southeast (Proctor, 1968) was not zoned (CDMG, 1980).

A more or less continuous, 300-meter long zone of ruptures and associated compressional features was observed just northwest of Whitewater P.O. (locality 22, Table 1 and Figure 2). Compressional features observed in the road pavements and alluvium and north-dipping fissures in the rather loose soil, strongly suggest that several centimeters of reverse or thrust faulting occurred along the pre-existing scarp in alluvium. Because the scarp is linear (N60°W trend) and the rupture zone is a fairly well-defined zone, we do

not agree with Sharp and others (1986) that these fractures are due entirely to shaking. Indeed, if the compressional features formed as a result of landsliding, we would expect the rupture zone (toe) to be concave to the north (the opposite is true) and other parts of the slide to be outlined by appropriate strike-slip (sides) and tensional fractures (crest). It is noted that the rupture zone lies on trend with the San Gorgonio Pass thrust fault of Smith (see Figure 2 and below).

San Gorgonio Pass fault (thrust).

A segment of this fault was mapped by Smith (1979b) based on a sinuous, south-facing scarp in young alluvium and subsequently shown on a Special Studies Zones map of the Whitewater quadrangle (CDMG, 1980). The fault was assumed by Smith to be a north-dipping thrust fault. Morton and others (1987) also map this fault as a north-dipping thrust, but identify it as the Garnet Hill fault. A similarly located fault is shown as a branch of the Garnet Hill fault on the small scale map of Matti and others (1985). However, they do designate a thrust fault to the west as the San Gorgonio Pass fault.

The San Gorgonio Pass fault of Smith was checked for ground rupture on July 11 in two areas, as was its projection to the east in Section 11. The scarps were verified but no ruptures were found (Figure 2).

"Devers Hill" fault

This north-northeast-trending fault was mapped by Smith (1979a) based on a moderately degraded northwest-facing scarp in older alluvium. This minor fault is shown on the SSZ map of Desert Hot Springs quadrangle (CDMG, 1980). We checked the entire southern half of the mapped trace, but could find no surface ruptures. However, a northwest-trending zone of minor extensional cracks was noted along and near the dirt road just east of the south end of the fault (Figure 2, locality 21). The crack zone was relatively narrow, perhaps 100 m long, and crossed the road at an acute angle. Because no slip could be measured on the cracks, they are not considered to be tectonic. Nonetheless, the cracks are anomalous in that they are not obviously related to lateral spreading associated with the existing topography or the road.

CONCLUSIONS AND DISCUSSION

Based on the evidence presented, we believe that discontinuous surface faulting occurred along a 4.5 to 9.5 km segment of the Banning fault in association with the July 8 earthquake. As much as 7 cm of right-slip was observed at Highway 62, diminishing rapidly to the east and west to less than a centimeter. Although accurate measurements of slip were difficult to make, the coincidence of rupture zones with linear scarps, the widespread existence of right-oblique extension on cracks, and clockwise orientation (left-stepping) of cracks relative to the fault-trend demonstrate right-slip faulting. The zone of rupture was more than 100 m wide in places and locally revealed features consistent with reverse and normal components of faulting. However, the large number of cracks associated with intense shaking (downslope movement, settlement) along the fault zone tended to obscure the clarity and continuity of tectonic rupture.

Fault rupture also apparently occurred along short segments of the Mission Creek and Garnet Hill faults. Rupture on the Garnet Hill fault was compressional and up on the north. This is consistent with previous faulting along the south-facing scarp in older alluvium. The minor left-lateral slip along the Mission Creek fault is anomalous in that the fault is a major branch of the right-lateral San Andreas system.

Minor afterslip may have occurred on the Banning fault at Highway 62, based on generally increasing offset measured on succeeding days (July 8 and 9). The increased number of cracks and width of the zone with time, also suggests afterslip. However, the fact that traffic continued to travel the highway during this period may account for these phenomena. The possible minor, left-lateral afterslip on the Mission Creek fault is even less certain.

The measured cumulative right-slip of cracks along the Banning fault at Highway 62 and the relatively perfect geodetic alignment of the highway curbs is seemingly anomalous. This caused Sharp and others (1986) to conclude that little or no surface faulting occurred along the Banning fault. They referred to this incipient faulting as "trace fracturing" and pointed out that the surface ruptures died out with depth, which was consistent with the absence of aftershocks in the upper 4 or 5 km of the surface. We do not find these facts so unusual and recognize that the ruptures we observed may be the result of shallow strain release triggered by shaking. In fact, if elastic strain had built up in the upper 1 or 2 km of the crust prior to construction of Highway 62, then the observed offset pavement (strain release) without overall misalignment of the highway is exactly what would be expected. We do not believe that triggered slip is unique to the North Palm Springs earthquake and believe it has occurred along segments of other faults, especially those that are known to be actively creeping. For example, both coseismic rupture and rapid creep events occurred on segments of the Calaveras fault that lay partly within and partly beyond the aftershock zones of the 1979 Coyote and 1984 Morgan Hill earthquakes (Hart, 1984 and unpublished data; Schultz 1984). It seems likely that surface faulting associated with those earthquakes was related to the triggered release of the shallow strain. The fact that the apparent surface faulting was restricted to the epicentral area of the NPS earthquake is not reason to assume that the surface ruptures were not triggered strain release. Moreover, it is not entirely certain that some of the surface ruptures did not extend to hypocentral depths. It seems premature to ascribe the rupture along the Banning fault (but not the Garnet Hill and Mission Creek faults?) to a new phenomenon. Therefore, we reject the term "trace-fracturing" as being unnecessary and confusing.

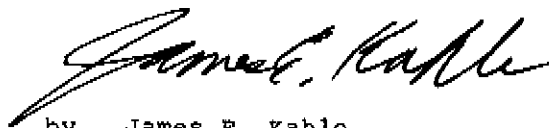
DISCUSSION OF SPECIAL STUDIES ZONES

Special Studies Zones (SSZ's) were established for the Banning, Mission Creek, Garnet Hill, and other faults in the Whitewater, Desert Hot Springs, and SE1/4 Morongo Valley quadrangles as required under the Alquist-Priolo Special Studies Zones Act (CDMG, 1974, 1980). These zones are shown in Figures 2, 3, and 4. The fault rupture associated with the NPS earthquake provided a good opportunity to test the effectiveness of SSZ's.

As can be seen from Figures 2, 3 and 4, all of the ruptures considered to be tectonic occurred within the SSZ's. Moreover, most of the rupture coincided with mapped traces of the Banning and Mission Creek faults. Only the short rupture segment of the Garnet Hill fault near Whitewater P.O. occurred near the SSZ boundary, but still was entirely within the SSZ.

From the viewpoint of the recent fault rupture, the SSZ maps appear to be adequate for development purposes. However, several fault segments zoned in the epicentral area may not meet our current zoning criteria of Holocene active and well defined (Hart, 1985), as suggested by the work of Clark (1984) and Matti and others (1985). When time permits, these and other SSZ's of the Transverse Ranges should be re-evaluated.

Report prepared 12/5/86; revised 2/23/87 and 8/7/87.



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Table 1. Field observations of surface ruptures associated with the July 8, 1986 North Palm Springs earthquake. Numbers correspond to numbered locations shown on Figures 2, 3, or 4.

Mission Creek Fault (Figure 4)

- (1). Two west-trending cracks in the southbound pavement of Highway 62; cracks are somewhat sinuous and about 16 m apart; on 7/11/86 yellow line was offset left-laterally nearly one centimeter at south crack and 6 to 7 mm at north crack. According to Rob Wesson and Randy Jibson (USGS, p.c., 7/11/86) slip on the north crack appeared to have increased 2 to 3 mm from the preceding day, suggesting possible afterslip. However, slip was greater than elsewhere along crack zone (see below) and was on thickest part of road fill, suggesting probable gravity effects. West-trending cracks also were noted to the east in pavements of northbound lanes and the Twentynine Palms Highway (Old HWY 62), as well as in adjacent dirt areas. Cracks in old highway painted orange to check for afterslip (but not re-checked). This zone of discontinuous cracks was at least 20 m wide and some of the cracks showed minor left-lateral extension. Crack zone could not be followed across the wash to the east, although Gary Rasmussen (p.c., 7/10/86) reported cracks with left-lateral extension in the ridge spur about 300 m east of HWY 62. The zone of cracks extended about 100 m to the west of HWY 62 in a cut surface of Plio-Pleistocene sedimentary rocks that was veneered with slope wash. The zone of cracks had a trend of N80°W and many cracks displayed left-lateral separation as much as 4 mm. A conjugate zone of cracks trending S45°W also was noted in the cut surface. Wesson and Jibson indicated that the main zone of cracks could be followed as much as 500 m west of the highway, but we were unable to verify this. The observed cracks roughly coincide with the projected trace of the Mission Creek fault, although expected sense of displacement was opposite of what would be expected. Nonetheless, the systematic and dominant sense of displacement (left-slip) indicates a tectonic cause.

Banning Fault (Figure 2)

- (2). Western limit of field checking along Banning fault; no cracks found between here and location 3.
- (3). Minor, discontinuous, hairline cracks along trace of fault in this area. Some cracks are along trend of fault here, but many trend clockwise 5° to 15° from fault trend. Few are en echelon, most are a few meters long and the distance between cracks is commonly greater than their length. Few are open more than 2 mm.
- (4). No cracks on fault trend here. Arcuate cracks along east side of road and in fill or alluvium east of road had 10 cm vertical

displacement (down to the southeast) and were parallel to the road at the top of the slumped area. These were due to slumping toward the creek east of the road.

- (5). Minor cracks across notches and gullies between here and location (6) are believed to be on the fault trace. These could be due to downslope movement but resemble cracks to the east along similar fault features.
- (6). Abundant shaking cracks resulting from slumping, fill failure, edge failure and shattered ground. Fault rupture may be present but is obscured by shaking effects. No cracks along well-exposed fault in gully to the east for a few hundred feet.

Banning Fault (Figure 3)

- (7). Cracks in alluvium on projection of fault trace. Few features from previous faulting present here but cracks occur in both older alluvium or fan debris and youngest active stream channel. Cracks not continuous or en echelon and do not appear to be rotated either clockwise or anticlockwise. Area between here and location (6) not investigated; dispersed, noncontinuous and ambiguous cracking reported by others (R.V. Sharp and D.M. Morton, personal communication; Sharp and others, 1986). Trench in Super Creek by Soil and Testing Engineers (1987) shows Holocene alluvium offset by 4 steeply dipping faults over a zone 62 meters wide.
- (8). Cracks in the thin soil of saddles at these points. Few cracks present on hillsides or in gullies between saddles. Cracks no wider than a few millimeters, some with a hint of right-lateral offset. Cracks commonly trend 5-15 degrees clockwise from fault trend.
- (9). En echelon, left-stepping cracks along both sides of a narrow trench-like feature. Cracks overlap and trend 5-15 degrees clockwise from fault trend (left-stepping). These are some of the better examples of tectonic fractures though none display right-lateral offset of more than 1 or 2 mm.
- (10). Discontinuous, isolated cracks along this stretch of fault. Some trend the same as fault, others are rotated clockwise from trend. Most cracks are 1-2 m long and difficult to find on grass and bush-covered slopes. Some cracks are a few meters one side or the other from the crushed zone along the fault but still tend to trend in the same direction as the fault. Offsets are minor, mostly extensional, and open less than 1 cm.
- (11). This previously unmapped "fault" trace is characterized by shattered ridges, edge breakage along the tops of slopes and complicated by extensive downslope movement. Although the majority of features seen here are attributed to shaking, two locations suggest surface faulting: a) Several cracks occur at one location, on the southeast nose of this linear ridge, which are en echelon with 2-3 cm of right-lateral offset and 3-4 cm extension which cannot be ascribed

to downslope movement as would be expected from purely shaking cracks. These cracks are so arranged that the uphill side moved relatively downward (eastward) due to the right-slip component. We envision no mechanism but lateral tectonic slip to accomplish this. b) In the alluvium east of this ridge (near Painted Hill Trail), left-stepping en echelon cracks had about 1 cm of oblique extension and trended about 15-20 degrees clockwise from the projected trend of the "fault".

- (12). Numerous isolated and discontinuous groups of cracks were found in a wide zone along this stretch of fault. Except for one location, none of the cracks had significant offset. In some cases the dispersion of cracks occurred in a zone wider than would be expected for a discrete fault rupture and most were probably caused by shaking. However, left-stepping cracks with as much as 3 to 4 cm (estimated) right-oblique slip were observed adjacent to Old Morongo Valley Road.
- (13). A series of cracks offset the northbound and southbound pavement of HWY 62 with significant right-lateral offset over a zone 145 meters wide. When first observed (7:15 AM, July 8, 1986) the southerly 5 cracks in a zone 46 m wide in the northbound lanes had a cumulative right-lateral offset of 6.4 cm on the west side of the paving and 5.7 cm on the east side measured normal to the road direction (N12E). These 5 cracks were remeasured on July 9, 1986 (9:15 AM) and the cumulative offsets were 6.2 cm (west side) and 7 cm (east side). Although the decrease in offset along the west side suggests some subsequent rotation of blocks between measurements, the average offset increased from 6 cm to 6.6 cm, suggesting possible afterslip. Four additional cracks were noted to the north of the first 5 on 7/9/86 (not noted previously). The northerly 2 of these showed 1 and 5 mm of right-lateral offset, giving a total cumulative slip of 7.2 cm. It is noted that the USGS measured 9 cm of cumulative right-slip for these same cracks, although an alignment survey of the road curb showed no significant misalignment of the pavement (Sharp and others, 1986) -- see text for discussion, herein. The cracks and displacements in the southbound lanes of HWY 62 were not measured, although significant right-lateral displacements were not obvious. Our incomplete notes indicate at least 3 large extensional cracks in a zone 24 m wide, the south crack showing some right-lateral offset and the others left-lateral offset. A large compressional hump between the southern cracks probably was caused by pavement migration due to shaking. However, a minor zone of left-stepping cracks could be followed between the hump area and the south crack of the northbound pavement. The differences in the features developed in the north and southbound lanes may be explained by the different thicknesses of fill, which is greater under the southbound lanes.
- (14). Most of the cracks in this area occur on or near older south-facing scarps. No en echelon cracks seen here but tension and compression cracks abundant. The cracks along the southernmost fault trace are

- north-dipping compression cracks, with 1-5 cm displacement accompanied by tension cracks further up the slope. One set of south-dipping compression cracks was noted with tension cracks upslope from that. The other scarps are characterized by tension cracks with rare 1-3 cm right-lateral offsets, mostly open downslope and broken or confused enough to preclude measurement. This zone of cracks was at least 60 m wide and is consistent in width, magnitude and sense of displacement with those at HWY 62.
- (15). Two sets of cracks in paved road, each about 8 m wide and about 20 m apart. The south zone displaces the road pavement about 3.5 to 4 cm right-laterally, whereas the north set shows left-lateral offsets (not measured). The intervening block of paving was rotated counter clockwise. Cracks in road were painted orange to identify possible afterslip (not rechecked).
- (16). Cracks along this stretch also occur on or near older north- and south-facing scarps. Not all scarps are shown on the map but are visible on air photos (WRD 5D6, photos 496 and 497, 6/17/66). The southern base of the hill was marked over most of its length by a series of compressional cracks which had enough overthrust component to obscure the amount of offset, probably in excess of 5-10 cm. Tension cracks were common on the slope above suggesting downslope movement. Toward the southeast, this compressional feature angled up the slope to merge with other cracks along a trough-like feature which may represent the main fault trace. Tension cracks, some with a hint of right-lateral offset, extended along the main trace but there may have been enough shattering along the zone to obscure more significant lateral offset. Tension cracks with a vertical component up both to the north and south were common. Other scarp-like features north of the main trace were marked by tension cracks. Few cracks occurred where no pre-existing fault (geomorphic) feature was present.
- (17). Zone (3-4.5 m wide) of minor, discontinuous cracks at or near base of north-facing scarp. Some show as much as 3-4 mm of right-lateral offset and some are left-stepping. Other discontinuous extensional cracks occurred part way up and at the top of the scarp (probably shaking features).
- (18). Narrow zone of discontinuous, minor, slightly sinuous cracks. Not obviously en echelon and most are open only 1-2 mm. Some are compressional with north side up a few millimeters. One crack had clear right slip of about 5 mm.
- (19). Broken water line along Diablo road where a hairline crack was present in pavement. Other extensional cracks present for about 120 m to the north in pavement; some cracks extended into the dirt at side of the pavement. The fourth crack from the south coincides with low, north facing scarp. Eleven of 14 cracks had minor right-lateral offset totaling 1.6 cm.

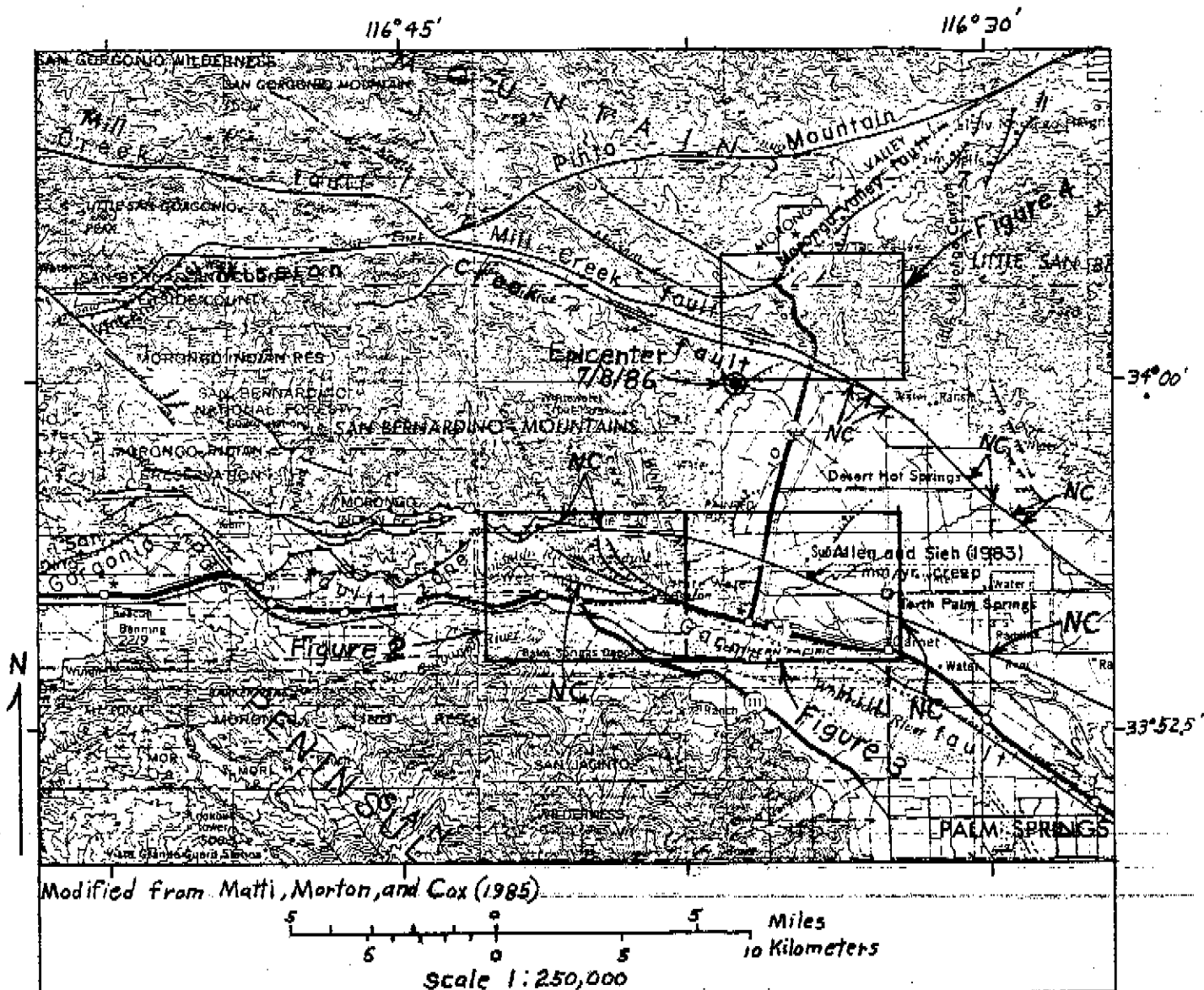
- (20). Zone of discontinuous cracks in alluvium to east of Diablo Road is about 2 m wide with as much as 10 mm of right-lateral offset recorded.

Devers Hill Fault (Figure 3)

- (21). No cracks were found along the southern half of the "Devers Hill" fault. A few extensional cracks in a west-northwest-trending zone, believed to be due to shaking, observed in the graded road and adjacent soils at the location indicated but could not be followed for any significant distance.

Garnet Hill Fault (Figure 2)

- (22). Cracks along [pre-existing] broad, south-facing scarp in older alluvium of Whitewater Canyon. Cracks found in a zone up to 10 m wide marked by both compressional and tensional features. Both roads which cross the scarp are paved and both were broken. The western road (Whitewater Canyon Road) had a compressional hump with 2-3 cm of overlap, north side up. Similar cracks were seen to the east along the scarp in alluvium. The hump in the eastern, branch road had about 6-7 cm of overlap, north side up, and similar reverse faulting was seen along the scarp to the east. Numerous boulders along the scarp were tossed or rolled from their resting places.



EXPLANATION

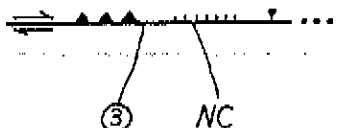

 FAULT. Arrows show direction of relative movement. Bar and ball on downdropped block. Hachures (on downdropped block) indicate fault scarp. Dotted where concealed. Teeth on upper plate of thrust or reverse fault. Number indicates location discussed in text. NC indicates location where no cracks were found on or near fault trace.

Figure 1. Index map showing the location of the July 8, 1986 North Palm Springs earthquake, the faults in the area, and selected locations mentioned in the text.

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DESERT HOT SPRINGS QUADRANGLE

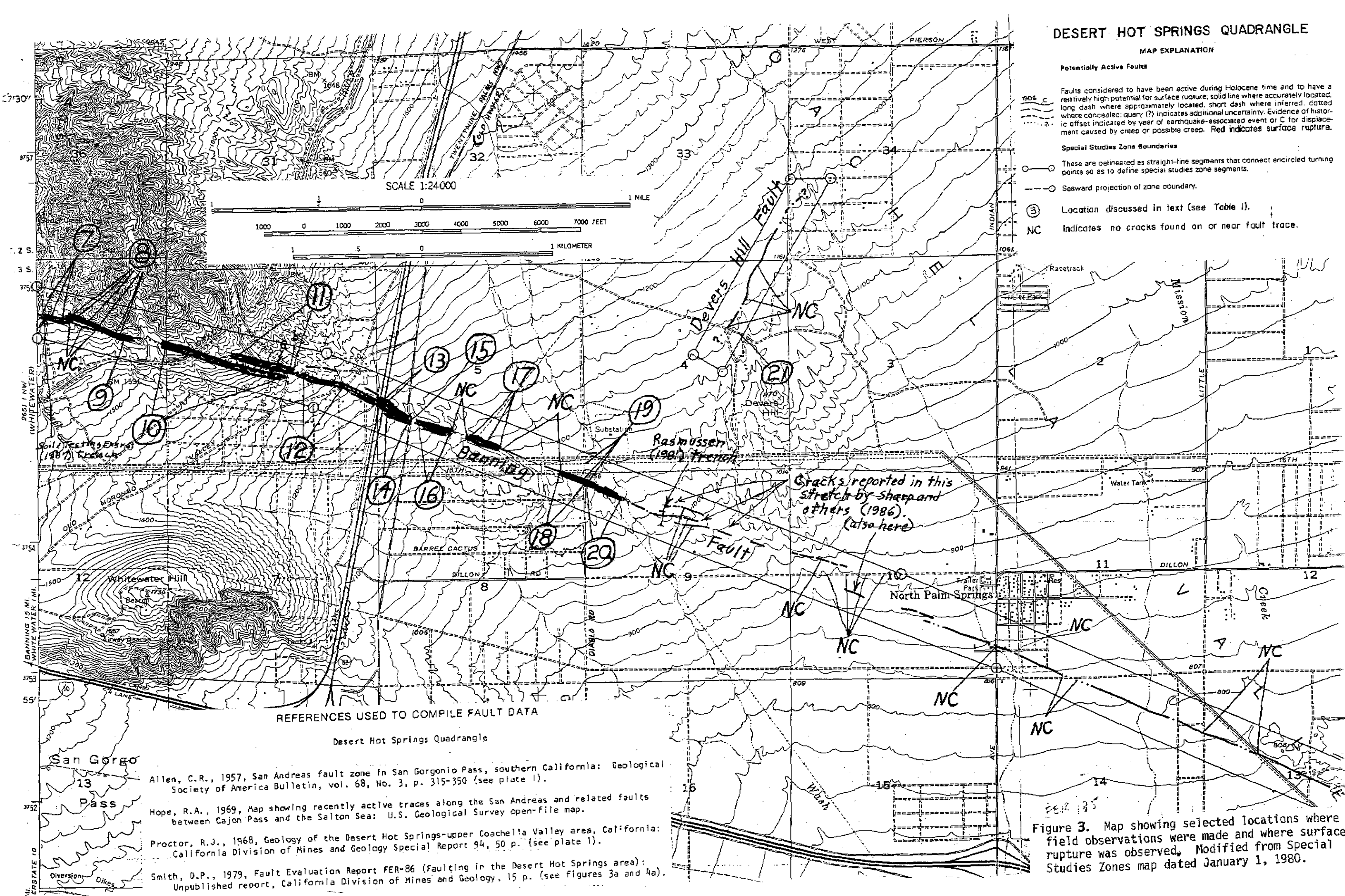
MAP EXPLANATION

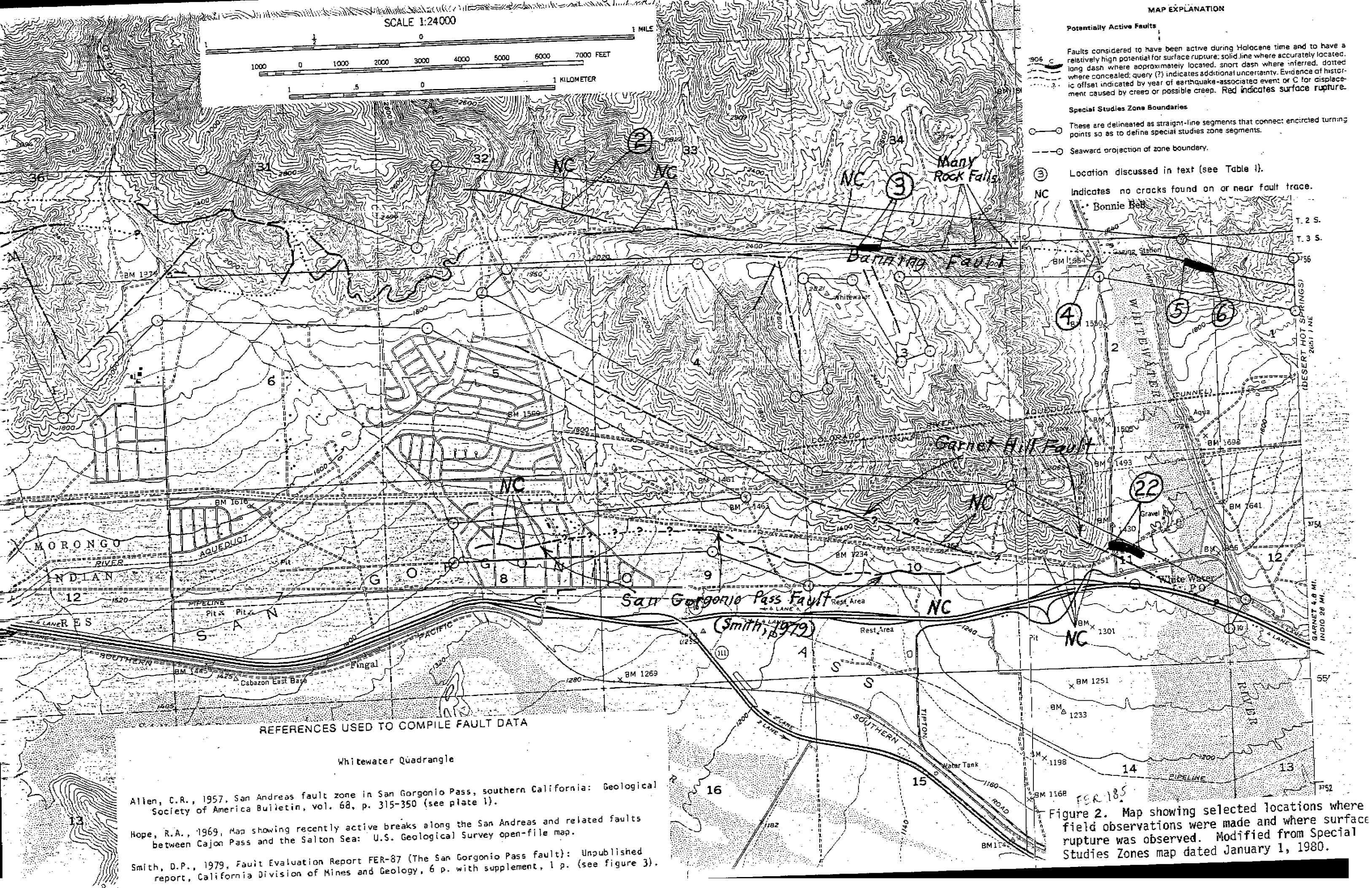
Potentially Active Faults

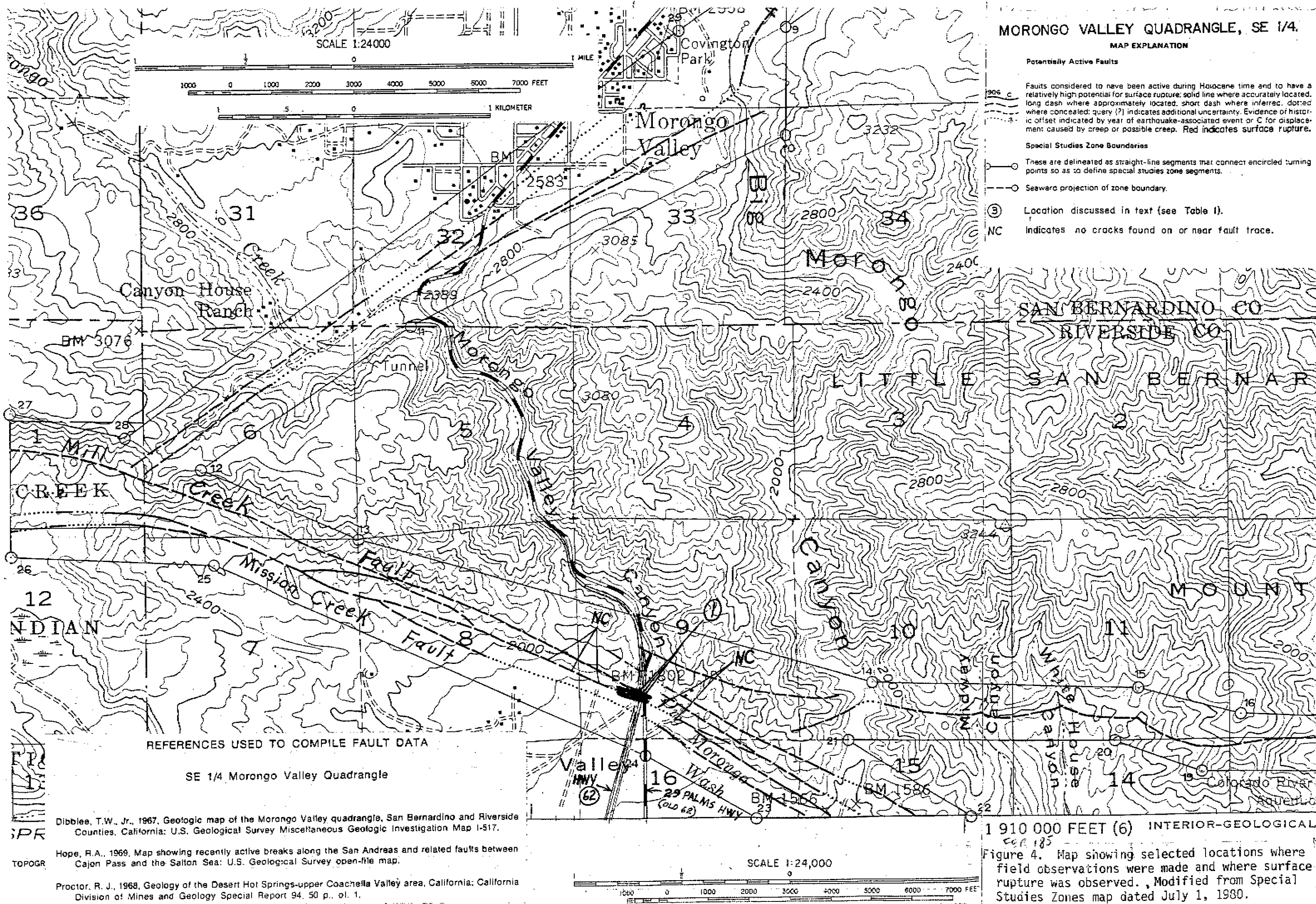
Faults considered to have been active during Holocene time and to have a relatively high potential for surface rupture: solid line where accurately located, long dash where approximately located, short dash where inferred, dotted where concealed; quarry (?) indicates additional uncertainty. Evidence of historic offset indicated by year of earthquake-associated event or C for displacement caused by creep or possible creep. Red indicates surface rupture.

Special Studies Zone Boundaries

- These are delineated as straight-line segments that connect encircled turning points so as to define special studies zone segments.
- Seaward projection of zone boundary.
- ③ Location discussed in text (see Table 1).
- NC Indicates no cracks found on or near fault trace.







MORONGO VALLEY QUADRANGLE, SE 1/4.

MAP EXPLANATION

- Potentially Active Faults**
 Faults considered to have been active during Holocene time and to have a relatively high potential for surface rupture: solid line where accurately located, long dash where approximately located, short dash where inferred, dotted where concealed; query (?) indicates additional uncertainty. Evidence of historic offset indicated by year of earthquake-associated event or C for displacement caused by creep or possible creep. Red indicates surface rupture.
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 Seaward projection of zone boundary.
- ③ Location discussed in text (see Table I).
- NC Indicates no cracks found on or near fault trace.

REFERENCES USED TO COMPILE FAULT DATA

- Dibblee, T.W., Jr., 1967, Geologic map of the Morongo Valley quadrangle, San Bernardino and Riverside Counties, California: U.S. Geological Survey Miscellaneous Geologic Investigation Map I-517.
- Hope, R.A., 1969, Map showing recently active breaks along the San Andreas and related faults between Cajon Pass and the Salton Sea: U.S. Geological Survey open-file map.
- Proctor, R. J., 1968, Geology of the Desert Hot Springs-upper Coachella Valley area, California: California Division of Mines and Geology Special Report 94, 50 p., pl. 1.

1910 000 FEET (6) INTERIOR-GEOLOGICAL
 Figure 4. Map showing selected locations where field observations were made and where surface rupture was observed. Modified from Special Studies Zones map dated July 1, 1980.

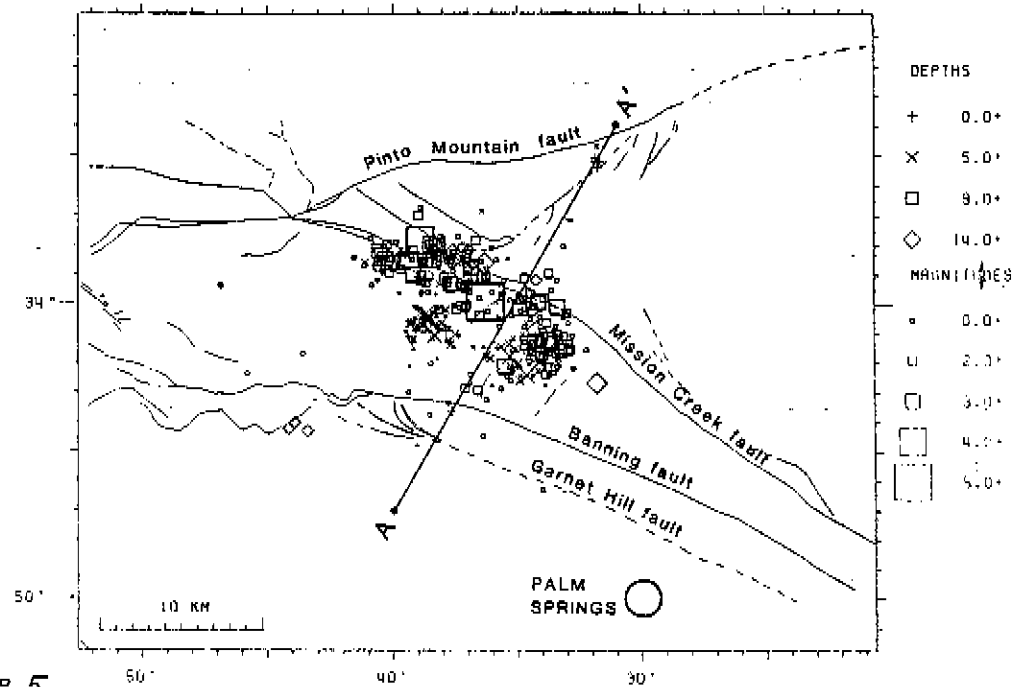


Figure 5.

FIG. 2. The epicentral locations of the main shock and located aftershocks of the 8 July 1986 North Palm Springs earthquake ($M_L = 5.9$). The line A-A is the projection line for the cross-section in Figure 3. Fault traces are after Matti *et al.* (1985). (From Jones and others, 1986, Fig. 2).

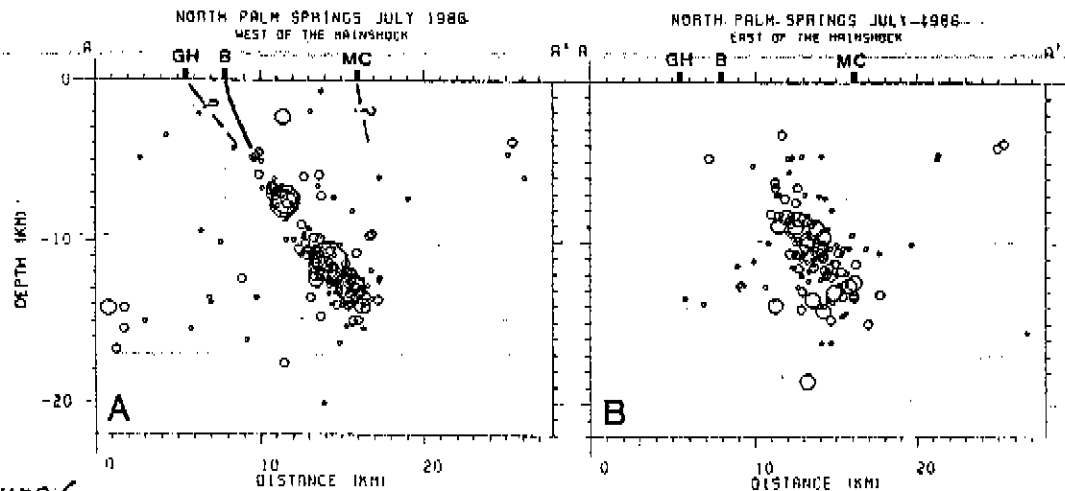
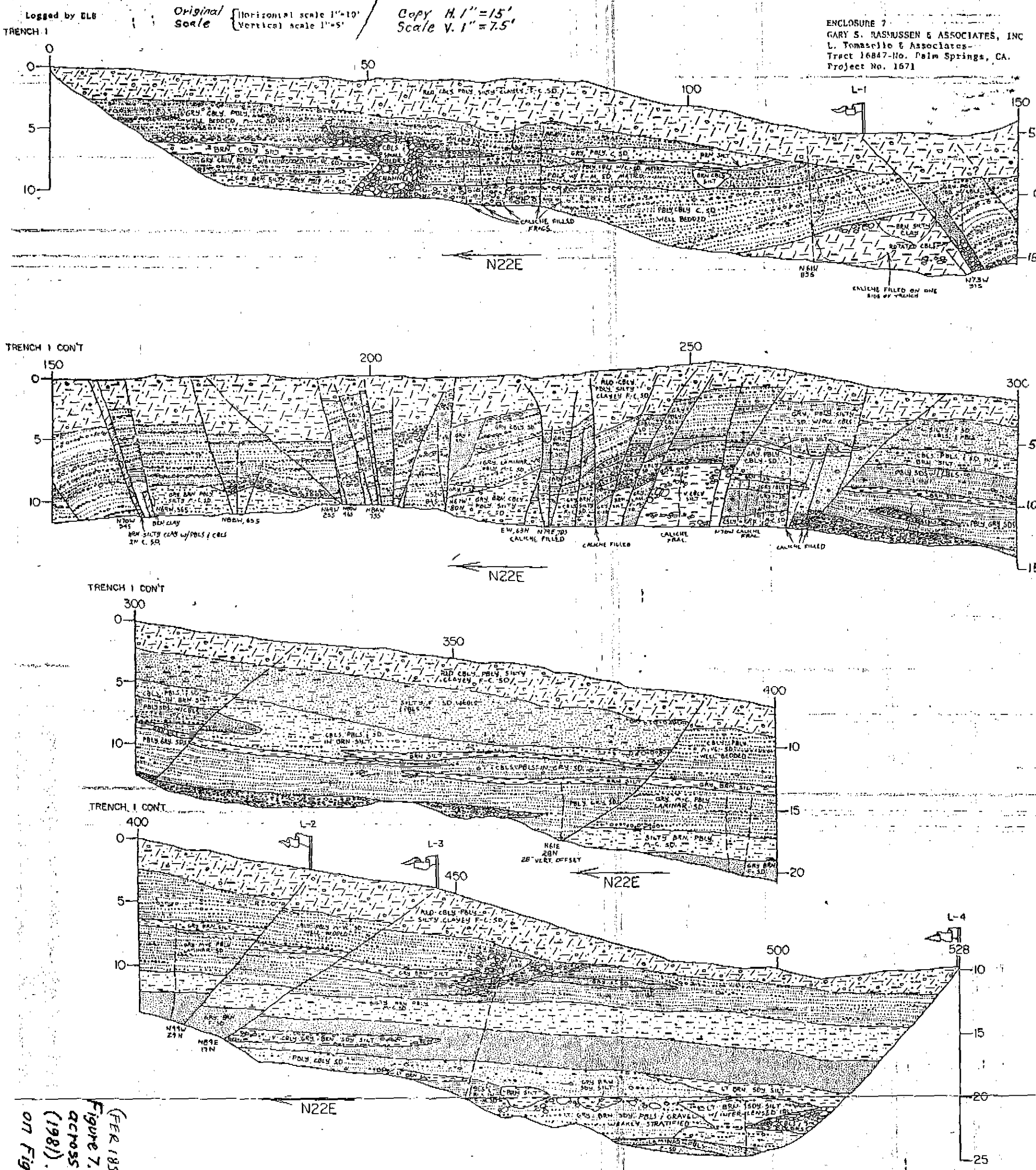


Figure 6.

FIG. 3. The depths of the main shock and located aftershocks of the 8 July 1986 North Palm Springs earthquake ($M_L = 5.9$) plotted against their projection onto the line A-A' shown in Figure 2. The points where the Garnet Hill (GH), Banning (B), and Mission Creek (MC) faults cross A-A' are marked. Aftershocks west of the main shock (A) and east of the main shock (B) are shown separately. (From Jones and others, 1986, Fig. 3).



(FER 185)
Figure 7. Reduced-scale log of trench across Banning fault, from Rasmussen (1981). Approximate location is shown on Figure 3,